# Emergence of overwintered larvae of eye-spotted bud moth, *Spilonota ocellana* (Lepidoptera: Tortricidae) in relation to temperature and apple tree phenology at Summerland, British Columbia

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## ABSTRACT

We recorded daily appearance of overwintered larvae of eye-spotted bud moth (ESBM), *Spilonota ocellana* (Denis & Schiffermüller) in spring 1992, 1994, and 1996 in an unsprayed apple orchard at Summerland, British Columbia, to relate larval emergence to degree-day (DD) accumulation and apple phenology. In all years the first larva was found between mid-March and early April, and none appeared after late April. Median emergence of larvae occurred when McIntosh apple trees were at early, tight-cluster stage of fruit-bud development. Larval head capsule measurements showed that ESBM usually overwinter as fifth and sixth instars, with a small proportion (≤6%) as fourth-instar larvae. In the laboratory we monitored emergence of non-diapausing overwintered larvae from apple branches incubated at 8.8, 9.4, 12.9, 15.0, 18.0, and 20.9 °C. A least-squares linear regression described emergence over this temperature range relatively accurately ($r^2 = 0.57$, $P < 0.05$) and a base temperature for emergence ($T_b$ = 1.0 °C ± 0.6) was extrapolated from this regression. Regression analysis indicated median emergence should require 154.6 ± 6.7 DD above 1 °C ($DD_{1\,°C}$). Using daily air-temperature maxima and minima and 1 March to start accumulating $DD_{1\,°C}$, the error between predicted and observed days to median emergence in the field was -6.7 ± 3.1 d; the regression model predicted early in every case. Using observed larval appearance on apples (1992, 1994, & 1996) and an iterative process, we determined that a combination of 6 °C as the $T_b$ and 1 January as a date to start accumulating $DD_{6\,°C}$, minimized the coefficient of variation for the three-year mean $DD_{6\,°C}$ accumulations (82.7 ± 3.5 $DD_{6\,°C}$) required for 50% of the larvae to appear in the field. While this latter DD index described observed emergence of larvae accurately, and its use may help improve management of ESBM, it should be validated using independent data before growers use it routinely.

**Key Words:** *Spilonota ocellana*, Tortricidae, larval development, phenology, degree days

## INTRODUCTION

The eye-spotted bud moth (ESBM), *Spilonota ocellana* (Denis and Schiffermüller), is a pest of apple (Gilliatt 1932, MacLellan 1978), blueberry (Gillespie 1985), cherry (Oatman *et al.* 1962), and prune (Madsen and Borden 1949) throughout fruit-growing areas in the northern hemisphere (Weires and Riedl 1991). ESBM is univoltine and larvae overwinter in hibernaculae on branches of host plants. Larvae crawl from hibernaculae in early spring to feed on leaves and blossoms. Pupation occurs in a nest of dead leaves and blossoms held together with silk.

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Adults emerge in early summer and lay eggs singly on leaves (Weires and Riedl 1991, McBrien and Judd 1998). Summer-generation larvae arising from these eggs often feed on fruit surfaces causing damage and discolouration beneath leaves attached to fruit with silk (Gilliatt 1932).

In North America, ESBM has a history of sporadic outbreaks in apple orchards (MacLellan 1978) because insecticides applied in summer against codling moth, *Cydia pomonella* (L.) often control it indirectly (Madsen and Downing 1968, British Columbia Ministry of Agriculture, Fisheries and Food 2004). As non-insecticidal methods like sterile male technique (Dyck and Gardiner 1992) or pheromone-based mating disruption (Judd *et al.* 1996, Judd and Gardiner 2004) have been implemented to control codling moth and leafrollers (Tortricidae) in British Columbia (B.C.), feeding damage by ESBM has increased (GJRJ unpublished data), mirroring reports from The Netherlands (Deventer *et al.* 1992). Therefore, control of ESBM in spring has become more critical. Insecticides applied in spring are often timed to control leafrollers and green fruit worms (Noctuidae), providing control of ESBM only indirectly (Madsen and Downing 1968, British Columbia Ministry of Agriculture, Fisheries and Food 2004). Therefore, strategies to control ESBM specifically need to be developed.

The ability to predict when overwintered larvae of ESBM appear in spring would be a useful tool in designing an integrated management programme. The phenology of ESBM larval emergence in spring has been related to apple phenology in other areas (Gilliatt 1932, Madsen and Borden 1949, Oatman *et al.* 1962) but this approach has not been validated in B.C., Canada, and may not provide consistent prediction of emergence on different species of host plant and on different varieties of fruit trees across different years. A temperature-based model to predict emergence of overwintered larvae may be a more useful approach as this technique has been applied successfully against other species of leafrollers in the Pacific Northwest (Brunner 1991). We describe emergence of overwintered larvae of the ESBM in relation to degree-day (DD) accumulations and apple tree phenology.

## MATERIALS AND METHODS

**Collecting and Handling Prunings**. Several hundred 30-cm branch sections were pruned from a mixed block of McIntosh, Delicious, and Spartan apple trees in an experimental apple orchard at the Pacific Agri-Food Research Centre (PARC) in Summerland, B.C. on 2 February 1992. No insecticides were applied to this orchard for at least five years preceding or during this study and it was heavily infested with ESBM larvae in 1991. Prunings consisting mainly of fruit-spur wood and excluding previous years' growth were transported to the laboratory, stored in cardboard boxes filled with moist sawdust, and held in darkness at 0.4 ± 0.5 °C until required.

**Diapause Termination**. Before assessing temperature-dependent emergence of overwintered larvae, it was important to ensure they had completed diapause so that some portion of diapause development was not included in any estimates of post-diapause development time. Prunings collected on 2 February and 1 March 1992, when apple buds were still dormant, were placed in a controlled-environment chamber at 19 °C under a 13:11 h L:D photoregime provided by Daylight fluorescent tubes. On each collection date, seventy 30-cm-long prunings were placed in a plastic basin (35 cm × 35 cm × 16 cm), covered with polyester organza and held in place with an elastic band that prevented larva from escaping but permitted air circulation. On 1 March, an equivalent length of pruned branch sections was removed from laboratory cold storage (0.4 °C) and set up identical to other pruning samples. Every 24 h, prunings were re-

moved from their basin and tapped sharply to dislodge active larvae onto a white cloth. The number of larvae collected daily was recorded and sampling was terminated when larvae went undetected for seven consecutive days after they began appearing.

**Emergence at Constant Temperatures**. On 7 May 1992, 66 days after being placed at 0.4 °C as part of the diapause study, ca. five hundred 30-cm sections of prunings were removed from cold and divided evenly among eight basins described previously. One basin of prunings was placed in each of seven separate controlled-environment chambers set at 3.8, 8.8, 9.4, 12.9, 15.0, 18.0, or 20.9 °C, respectively, each with a photoregime of 13:11 h L:D. One basin of prunings was returned to 0.4 °C. Constant-temperature conditions were chosen to approximate the range of air temperatures and photoregime normally experienced by ESBM larvae during spring in the Okanagan Valley. When prunings were placed in controlled-temperature chambers on 7 May 1992, larvae in the field had completed emergence.

One larva emerged on day 54 from prunings incubated at 0.4 °C and three larvae emerged on days 9, 18, and 46 from prunings incubated at 3.8 °C. Therefore, on 1 July, 55 d after incubation, prunings were transferred from 0.4 and 3.8 °C to the 18 °C constant-temperature incubator to determine if larvae would emerge at the higher temperature and if their emergence times would be shorter than those placed at constant 18 °C from the outset.

**Linear Regression-based Emergence Model**. A linear DD emergence model, lower threshold base temperature ($T_b$), and the DD requirements for median (50%) emergence of larvae were determined analytically using linear regression techniques (Campbell *et al.* 1974) applied to laboratory-derived constant-temperature emergence data. Emergence time in days for each larva at each constant temperature was converted to an emergence rate by taking the reciprocal (developmental rate = 1 / days to emerge). Emergence rates for all larvae at each temperature were regressed against temperature using least-squares linear regression analysis (Zar 1984). Extrapolating this linear regression through the $x$-axis gave the theoretical lower developmental threshold base temperature (Arnold 1959). The number of DDs needed for emergence of 50% of the larval population was determined by taking the reciprocal of the slope of the linear regression line (Campbell *et al.* 1974). Standard errors for estimates of $T_b$ and DD totals were calculated as described by Campbell *et al.* (1974). Two ESBM larvae emerged within 1 d of incubation at 20.9 °C. The emergence rates for these two larvae were considered outliers and excluded from linear regression analysis in order to maintain homogeneity of variance (Zar 1984).

**Phenology of Larval Emergence in the Field**. Prunings infested with overwintered ESBM larvae were collected from the experimental apple orchard in early March 1992, 1994, and 1996. Collections were made while apple buds were dormant and before ESBM larvae had started to crawl from overwintering hibernaculae. As before, prunings mainly consisted of fruit-spur wood and did not include previous years' growth. Wood was cut into 30-cm-length pieces and placed in cylindrical mesh bags (length = 60 cm, diameter = 25 cm) made from polyester organza and tied at both ends with string. Each of eight mesh bags was filled with 30 prunings and suspended 1.8 m above ground from an apple tree in the experimental orchard. Bags were suspended from a branch on the north side of trees to minimize exposure to direct sunlight. Each bag was hung from a separate tree in the lower half of the canopy but above the lowest scaffold branch. No bags were hung in the border row of trees.

Each day, each pruning was removed from its bag and tapped sharply on a white plastic tray to dislodge active larvae. The inside of each bag was checked for larvae after which prunings were returned to bags

and rehung in trees. Numbers of larvae collected from each bag were recorded, and the total number collected from all bags was pooled each day. Bags were checked until no larvae were counted for seven consecutive days after the first larva appeared. The phenology of a sample of 20 fruit buds on McIntosh apple trees in the study site was recorded every two to three days. Fruit-bud phenology is described by British Columbia Ministry of Agriculture, Fisheries, and Food (2004).

**Instars of Overwintered Larvae**. Head capsule widths of overwintered larvae were measured from prunings collected on 1 March 1992 as part of the diapause termination study, and from prunings used to monitor larval emergence in the field during 1994 and 1996. Each larva that emerged from prunings was preserved in 70% ethanol and its head capsule width was measured to determine instar (Gilliatt 1932). Gilliatt (1932) did not provide estimates of variation for the head capsule width of each of the seven larval instars, therefore, the midpoint between the mean head capsule width for each successive instar was used as the range for classifying each instar.

**Temperature Measurement and DD Accumulation**. Hourly air temperatures in the PARC apple orchard were recorded throughout the study using a DP-212 datapod (Omnidata™, Logan, UT, USA) housed at 1-m height in a Stevenson screen. Degree-day summations were calculated by fitting a sine wave (Allen 1976, case 4) to daily air-temperature minima and maxima using the computer programme described by Higley *et al.* (1986). Degree-day summations were calculated in 1992, 1994 and 1996 using all possible combinations of lower threshold base temperatures consisting of 1, 2, 3, 4, 5, 6, 7 or 8 °C, and 1 January, February, or March as dates to start summation. Accumulations from each start date up to the Julian Day (JD) on which 50% of the larvae appeared in the phenology sampling performed above were calculated. Temperatures <9 °C were chosen as possible base temperatures because the majority of larvae incubated at constant temperatures <8.8 °C in the laboratory never emerged. No upper temperature threshold was set. The coefficient of variation (CV) among these DD calculations for individual years was calculated for each combination of base temperature and starting date. The combination of base temperature and starting date which gave the lowest CV (Arnold 1959) was chosen to generate DD summations that best described the observed cumulative larval emergence in 1992, 1994 and 1996. Cumulative larval emergence data (1992, 1994, and 1996) was plotted against these DD summations and a cumulative Weibull function was fitted to this scatter plot (McBrien and Judd 1998).

**Statistical Analyses**. All statistical analyses were performed with SigmaStat® (Version 3.0.1, SYSTAT Software Inc., Richmond, California, USA) and all experiment-wise error rates were set at $\alpha = 0.05$.

## RESULTS AND DISCUSSION

**Diapause Termination**. The average number of days required for ESBM larvae to appear from prunings incubated at 19 °C following collection at various dates or removal from cold storage are shown in Table 1. Fifty percent of the 74 larvae coming from prunings collected on 2 February appeared in 9.7 d, whereas 50% of the 66 larvae coming from prunings collected on 1 March did so in 6 d. This difference represents a 38.1% decline in days to appear following 28 d of field aging. By comparison, 50% of the 83 larvae coming from prunings collected on 2 February but stored at 0.4 °C for this 28-day period, did so in 8.6 d, representing an 11% decline in days to appear compared with larvae on prunings collected 2 February, but immediately incubated at 19 °C (Table 1).

Knowing when diapause terminates is critical to construction and application of any DD model because it establishes a

**Table 1.**
Time needed to emerge (days) at 19 °C for larvae of *S. ocellana* collected from the field or removed from laboratory cold storage in February and March 1992.

| Collection and incubation dates | Median emergence time | | Mean (± SD) emergence time | |
|---|---|---|---|---|
| | Laboratory stored[1] | Field collected | Laboratory stored[1] | Field collected |
| 2 February | - | 9.7 | - | 10.8 ± 2.3 |
| 1 March | 8.6 | 6.0 | 9.0 ± 2.3 | 7.0 ± 2.3 |

[1] One half of first field collection (2 February) was placed in laboratory cold storage (0.4 °C) and removed at time of second field collection (1 March)

biologically relevant time at which these accumulations might start and it ensures more accurate determination of post-diapause development times. Whether overwintering larvae of ESBM undergo true obligatory diapause (Danks 1987) is not known nor was it determined because prunings were collected too late in winter to investigate this aspect of larval development. Those cues that might end diapause in ESBM are not known, but in temperate insects there is often a minium time requirement before post-diapause development begins (Danks 1987). Whatever cues are necessary to break diapause in ESBM, larvae clearly develop in February if temperatures are appropriate. As diapause progresses or terminates in many species, observed times for the diapausing life stage to hatch or emerge often shortens and becomes more synchronous (Tauber and Tauber 1976). Thus, a decline in average days to appear or emerge during incubation that begins at different times in winter is often an outward manifestation of diapause progression (Judd *et al.* 1993, 1994). Our observation that average time until larvae appeared on prunings incubated at 19 °C after storage at 0.4 °C from 2 February to 1 March, was only 11% shorter than those incubated at 19 °C on 2 February (Table 1), suggests most larvae were out of diapause by 2 February. By comparison, larvae stored in the field during this same period appeared sooner when placed at 19 °C on 2 March (Table 1) than on 2 February, indicating they had probably undergone some post-diapause development in the field. Therefore, most ESBM larvae probably complete diapause by 2 February and undergo post-diapause development when temperatures are above 0.4 °C as they were in the field at this time of year. Collectively, these data indicate larvae on prunings removed from cold storage after 1 March were suitable for studies on post-diapause development and 1 February might be a suitable time to start DD accumulations in the field.

**Emergence at Constant Temperatures**. The relative frequency of days to appear for larvae incubated at constant temperatures between 8.8 and 20.9 °C are shown in Fig. 1. The median and mean days to appear are similar at each temperature indicating that each overall distribution is approximately normal (Zar 1984). After 54 d of incubation at 0.4 and 3.8 °C, only 1 and 3 larvae had appeared on these prunings, respectively (Fig. 1). On day 55 these prunings were transferred to 18 °C and after transfer, 50% of 65 and 33 larvae, respectively, appeared within 8.7 and 6.2 d. These respective median times were 0.2 and 2.7 d shorter than times taken for 50% of the larvae incubated at constant 18.0 °C to appear (Fig. 1). Obviously, there was little or no development occurring at 0.4 °C, while a 2.7-d shorter median emergence time indicates some development probably occurred during 54 d of incubation at 3.8 °C.

**Linear Regression-based Emergence Model**. Linear regression (Fig. 2) of the relationship between emergence rates ($y$) and temperatures ($x$) between 8.8 and 20.9 °C ($y = 0.0066\ x - 0.0067$) provided a reasonable description ($r^2 = 0.57$, $P < 0.05$) of

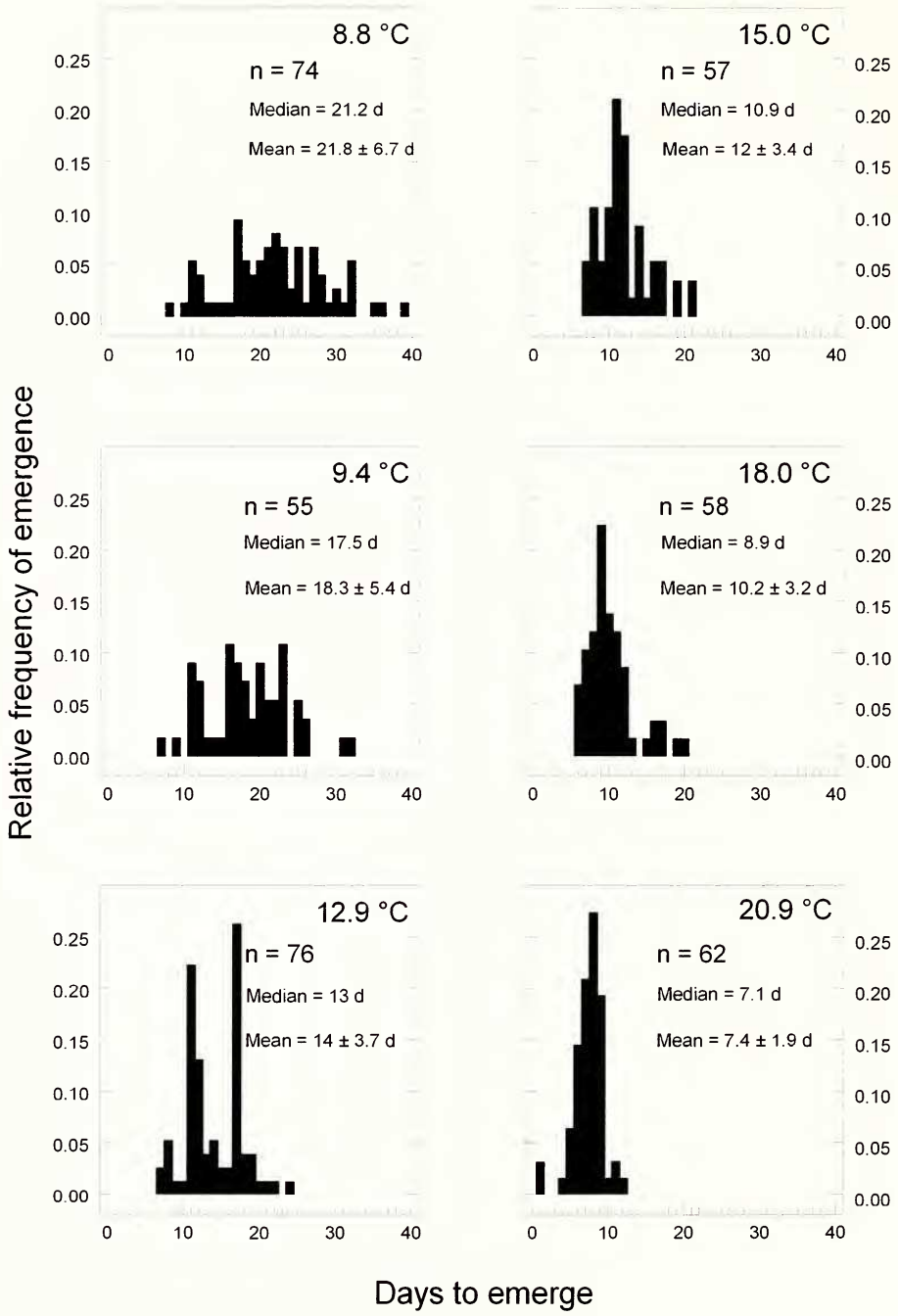


**Figure 1.** Relative frequency histograms for daily emergence of post-diapause overwintered larvae of *S. ocellana* held at various constant temperatures.

the observed emergence data.

Extrapolation of this line to the *x*-axis provides a theoretical estimate (1.0 ± 0.6 °C) for the lower developmental threshold ($T_b$). The reciprocal of the slope of this regression line indicates that half the population of ESBM larvae should appear in 154.4 ± 6.7 $DD_{1\,°C}$.

**Phenology of Larval Emergence in the Field**. Fig. 3 shows relative frequency

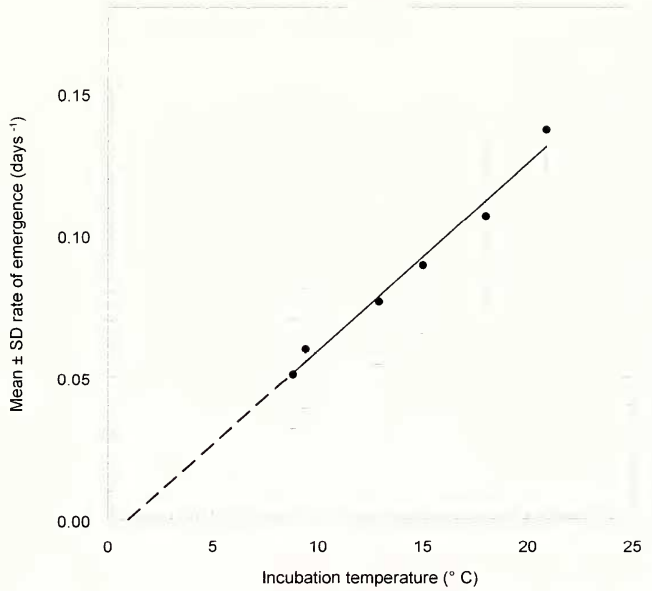


**Figure 2.** Mean (± SD) emergence rates (solid circles ) of post-diapause overwintered larvae of *S. ocellana* at temperatures between 8.8 and 20.9 °C. A least-squares regression line (solid line) was fitted to individual larval emergence rates and extrapolated (dotted line) to the *x*-axis to estimate the base temperature threshold, $T_b$ (1.0 ± 0.6 °C).

curves for daily larval emergence each year. The dates for first emergence ranged from JD 75 (15 March) in 1992 to JD 96 (5 April) in 1996. Fifty and 100% emergence occurred between 0 - 14 and 25 - 35 d, respectively, after the first larva was detected each year. The first ESBM larva was found in the field when McIntosh apple trees were at early green-tip stage of bud development. Fifty and 95% larval emergence consistently occurred in early, tight-cluster and late, pink-bud stages, respectively (Table 2). All larvae had emerged shortly after bloom began. Previous observations on appearance of overwintered ESBM larvae in spring have noted that larvae begin to emerge soon after buds begin to open (Gilliatt 1932, Madsen and Borden 1949, Oatman *et al.* 1962).

**Instars of Overwintered Larvae.** Among the 66 larvae which appeared on prunings incubated in the laboratory after field collection 1 March 1992 (Table 1), 7, 70 and 23% were fourth, fifth, and sixth instars, respectively. Among the 178 larvae that appeared on prunings during field observation in 1994, 5, 70 and 25% were fourth, fifth, and sixth instars, respectively. The distribution of instars in 1994 was not significantly different ($\chi^2 = 0.614$, df = 2, $P = 0.736$) than the distribution of larval instars observed in the laboratory in 1992. In 1996, 6, 43, and 51% of the 64 larvae observed on prunings in the field were fourth, fifth, and sixth instars, respectively. While the proportion of fourth instars in 1996 was similar to that in 1992 and 1994, the overall distribution of instars in 1996 was significantly different from 1992 ($\chi^2 = 11.778$, df = 2, $P < 0.003$) and 1994 ($\chi^2 = 16.677$, df = 2, $P < 0.001$) because of a greater percentage of sixth instars in 1996. In 1994, 50% of fourth, fifth, and sixth instars appeared in the field by JD 97, 101, and 102, respectively; in 1996 they occurred on JD 106, 108, and 102, respectively. When all larval instars are considered together 50% appeared by JD 100 in 1994, and JD 106 in 1996 (Table 2, Fig. 3).

ESBM has seven larval instars, and on apple, larvae reportedly overwinter in the fifth instar (Gilliatt 1932, LeRoux and Reimer 1959, MacLellan 1978). However, Gilliatt (1932) observed that some larvae also overwinter in the fourth and sixth in-

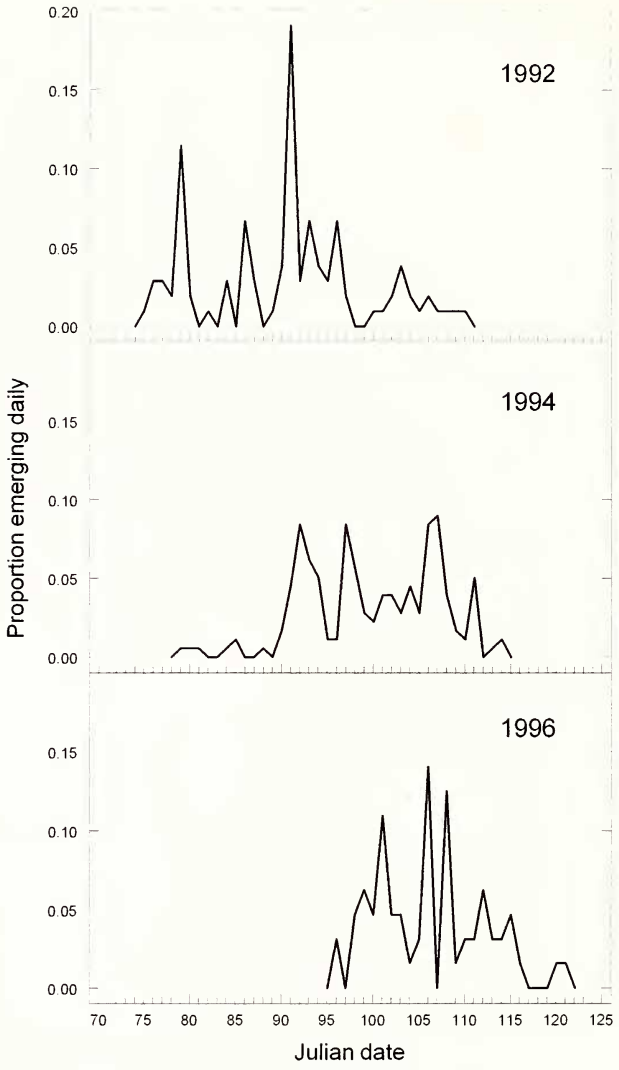


**Figure 3.** Percent of overwintered larvae of *S. ocellana* emerging daily in 1992, 1994, and 1996. Total larvae emerged in 1992, 1994, and 1996 were 105, 178, and 64, respectively.

stars. Oatman *et al.* (1962) reported that on sour cherry ESBM larvae entered hibernaculae in autumn as third instars and then moulted sometime before appearing in spring. According to Borden and Madsen (1949), on prune ESBM larvae began to construct hibernaculae as fourth instars but moulted during this process, and overwintered as fifth instars. While the present study supports the findings of Gilliatt (1932), because no measures of variation for the mean head capsule widths used to categorize larvae have been provided by any study, it is currently impossible to attach complete certainty to any of these results.

**Validating the Linear Regression-based Emergence Model**. Using our linear regression model (Fig. 2), a 1 °C base temperature, and 1 March to start DD accumulations, 50% of ESBM larvae were predicted to appear by JD 87, 90 and 100 in 1992, 1994, and 1996, respectively. Predicted dates for 50% emergence were 4, 10, and 6 d early, respectively (Table 2). The mean (± SD) error between predicted and observed dates of 50% emergence was -6.7 ± 3.1 d. The number of $DD_{1\,°C}$ accu-

**Table 2.**
Relationship between specific observed cumulative percentiles of emergence of overwintered *S. ocellana* larvae, fruit-bud phenology of McIntosh apple trees and degree-day accumulations above 1 °C ($DD_{1°C}$) starting 1 March in 1992, 1994, and 1996.

| Cumulative emergence percentile | Year | Julian date | $DD_{1°C}$ | Percentage of fruit buds at each development stage [1] | | | |
|---|---|---|---|---|---|---|---|
| | | | | Green tip | Tight cluster | Pink | Blossom |
| 5% | 1992 | 77 | 93.2 | 100 | | | |
| | 1994 | 90 | 151.8 | 100 | | | |
| | 1996 | 98 | 140.7 | 100 | | | |
| 50% | 1992 | 91 | 177.0 | 90 | 10 | | |
| | 1994 | 100 | 226.8 | 90 | 10 | | |
| | 1996 | 106 | 209.5 | 95 | 5 | | |
| 95% | 1992 | 106 | 287.7 | | | 100 | |
| | 1994 | 111 | 339.0 | | | 100 | |
| | 1996 | 115 | 276.3 | | 10 | 90 | |
| 100% | 1992 | 110 | 329.4 | | | 90 | 10 |
| | 1994 | 114 | 368.3 | | | 95 | 5 |
| | 1996 | 121 | 320.1 | | | 70 | 30 |

[1] Percentage based on 20 fruit buds. Fruit-bud phenology based on B.C. Ministry of Agriculture, Fisheries, and Food Tree Fruit Production Guide (1996)

mulating after 1 March to various percentiles of observed emergence of larvae in the field were calculated and shown to be equally variable to 50% emergence (Table 2). Clearly our laboratory-derived linear development model predicted median larval emergence about 20% too early. This deviance may arise because development of ESBM larvae in spring may not be solely related to temperature in the same way life stages like eggs or pupae appear to be (McBrien and Judd 1998). Alternatively, overwintering larvae may have temperature thresholds for movement or feeding activity higher than the $T_b$ we calculated from regression analysis (Fig. 2). If this were the case, overwintering larvae may have completed diapause or post-diapause development by the dates predicted by the regression model, but if temperatures were too low for them to move or feed they may not have appeared on prunings until temperatures were suitable. Accumulating DD before 1 March, when diapause was likely over (Table 1), would only have made the errors of prediction greater, thus it seems a base temperature of 1 °C may be incorrect for predicting larval activity in spring.

**Observed DD Accumulations**. The CV associated with each observed DD summation calculated using all possible combinations of three starting dates (1 January, February or March) and $T_b$ (1 - 8 °C) to describe observed 50% emergence in the field is shown in Fig. 4. The lowest CV for this one event was obtained with a starting date of 1 January and $T_b$ of 6 °C (Fig. 4). This $T_b$ is not unlike that of two sympatric species of leafroller in the Pacific Northwest, *Pandemis pyrusana* Kearfoot and *Choristoneura rosaceana* Walker, that have a $T_b$ of ≈5 °C (Brunner 1991) and emerge in spring after overwintering as second- or third-instar larvae. The empirically-derived CV-based approach gave a mean of 82.7 ± 3.5 $DD_{6°C}$ from 1 January to 50% emergence, with a CV of 4.3 (Fig. 4), whereas the mean number of $DD_{1°C}$ from 1 March to 50% emergence was

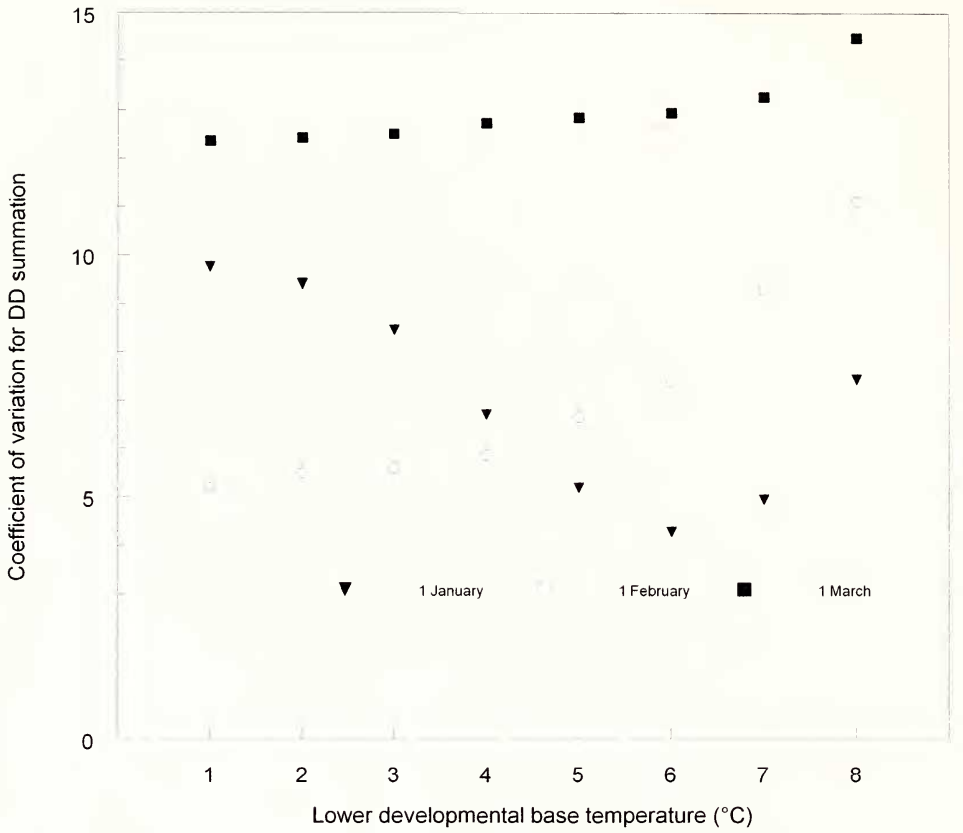


**Figure 4.** Coefficients of variation associated with three-year average (1992, 1994, and 1996) degree-day summations from various starting dates (1 January, 1 February, and 1 March) to 50% observed emergence of overwintered larvae of *S. ocellana* using different lower base temperatures between 1 and 8 °C.

204.4 ± 25.3 and more variable with a CV of 12.4 (Fig. 4). To provide a methodology for calculating $DD_{6\,°C}$ indices associated with any percentile of observed emergence in the field we plotted observed cumulative larval emergence against $DD_{6\,°C}$ accumulations after 1 January and a cumulative Weibull function accurately described ($R^2 = 0.89$, $P < 0.05$) this relationship (Fig. 5). It should be noted that, although this Weibull function described observed emergence with less variation than the laboratory-derived linear regression and 1 °C $T_b$ (Table 2), the accuracy with which this empirically-derived nonlinear equation can predict future events needs to be validated with independent data. The difference between a $T_b$ derived using this empirical approach and the laboratory-derived DD model may be explained partly by the difference in handling of the prunings used to monitor larval emergence in the laboratory at constant temperatures and to monitor emergence in the field. In the laboratory, prunings were stored at 0.4 °C in total darkness for ca. 3 mo while prunings used to monitor emergence in the field were removed from trees ca. 10 d before larval emergence began naturally. Factors besides thermal summations, such as light, chill units, or moisture which trigger flower bud development, may also determine when overwintering ESBM larvae emerge. Any potentially unknown factors that affect emergence are inherently incorporated within any empirical model even if they are not understood. For whatever reason, our data suggest a developmental model generated from laboratory data only, may not be suitable for

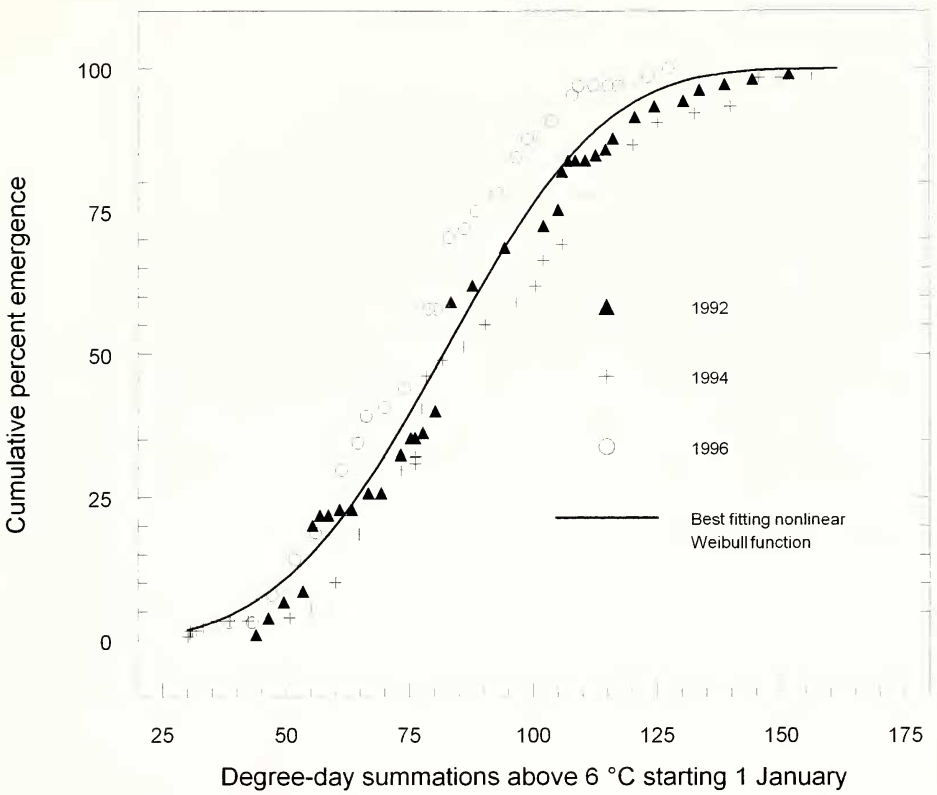


**Figure 5.** Observed cumulative percent emergence of overwintered larvae of *S. ocellana* in 1992, 1994, and 1996 (data points). Solid line is best fitting ($P < 0.05$) cumulative Weibull function ($\hat{y} = 100 \times ( 1 - e^{-(x/90.5)})^{3.6}$ used to describe emergence where $x = DD_{6\,°C}$ after 1 January.

describing processes which trigger activity of ESBM larvae during winter and their appearance in spring. On the other hand DD indices generated from observed field data may prove useful in management of ESBM (Fig. 5).

**Phenology Models and Management of ESBM**. Median emergence of ESBM larvae appeared to be closely linked to fruit-bud phenology of McIntosh apple trees (Table 2), occurring consistently at the early, tight-cluster stage of fruit-bud development. Currently, conventional insecticide applications at tight cluster, pink, or petal fall, or applications of *Bacillus thuringiensis* (Berliner) at full bloom which target leafrollers, are recommended as indirect controls for ESBM in spring (British Columbia Ministry of Agriculture, Fisheries, and Food, 2004). The latter control is one most commonly used by organic producers in the Okanagan and Similkameen Valleys (Judd unpublished data). During this study, emergence of ESBM larvae was complete by early bloom, which is very likely too late for control because most larvae enclose themselves within feeding shelters made from blossoms. Our observations indicate application of residual insecticides to McIntosh apples at the pink stage would have reached 90 - 100% of the larvae (Table 2), well before they enclose themselves in feeding shelters. This is consistent with observations by Madsen and Downing (1968) that azinphosmethyl applied to McIntosh apples in the early pink stage provided good control of ESBM in spring. However, recommendations to spray at pink of McIntosh would not necessarily be appropriate on apple varieties that flower at different dates, which is a common oc-

currence in montane growing regions.

A temperature-based model that can consistently predict 90 - 100% emergence of overwintering ESBM larvae, independent of flowering dates, should have greater application to different apple varieties, years, regions and to host plants other than apple. While this study has not yet provided that model, if the equation given in Fig. 5 can be validated with independent data then it may be useful in predicting any percentile of larval emergence in spring that is deemed necessary for control purposes. Such an equation and models of adult emergence, flight, and oviposition during summer combined with a pheromone-based monitoring program (McBrien and Judd 1998), may provide a more specific management programme for ESBM.

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